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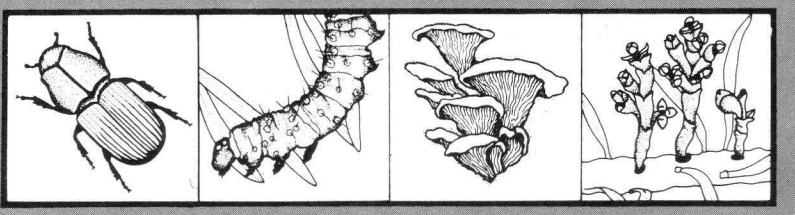

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EFFECTS OF SOIL FUMIGATION ON CONIFER SEEDLING PRODUCTION AT THE USDA FOREST SERVICE NURSERY, COEUR D'ALENE, IDAHO

by

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ABSTRACT

Effects of soil fumigation with dazomet (granular) and methyl bromide chloropicrin on soil pathogen populations and disease occurrence on, and growth of, bareroot western white pine, Douglas-fir, and western larch seedlings were evaluated at the USDA Forest Service Nursery, Coeur d'Alene, Idaho from 1986-88. Both fumigants initially eliminated soil pathogens. However, *Fusarium* and *Pythium* spp. reinvaded dazomet-treated soil during the 2-year crop cycle, although their numbers were not high. Little reinvasion occurred in soil treated with methyl bromide/chloropicrin. Diseases of seedlings grown in both fumigated and non-fumigated soil was low. However, greater amounts of root infection by *Fusarium* spp. on seedlings occurred in non-fumigated soil. Seedlings grown in fumigated soil were often taller than those grown in non-fumigated soil. Implications of these findings on bareroot seedling production at the nursery are discussed.

INTRODUCTION

The USDA Forest Service Nursery in Coeur d'Alene, Idaho produces from 8-20 million bareroot conifer seedlings annually for reforestation of federal lands. Several years ago, growers at the nursery instituted a program of soil fumigation using a mixture of methyl bromide (67%) and chloropicrin (33%) - MBC. Fumigation was designed to reduce potential damage on conifer seedlings from soil-borne pathogens, particularly those in the genus *Fusarium* (Williams 1976). Since its inception in the mid-1970s, soil fumigation has been performed several times throughout most production areas of the nursery. Fumigation is normally conducted in late summer or early fall when soil conditions, such as temperature and moisture, are conducive to penetration of the fumigants (Kolbezen and others 1974; Munnecke and Van Gundy 1979). Sowing of fumigated fields normally occurs the following spring. Cycles on most production fields include a 2-year conifer crop, followed by 1 year of fallow and usually cover crops of oats, rye, or both. Soil fumigation usually occurs a few months after the cover crop is incorporated.

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MBC is a non-selective biocide that usually kills all soil organisms which it contacts (Ebben and others 1983; Munnecke and others 1978). After fumigation with MBC, soil is usually reinvaded by microorganisms rather quickly (Danielson and Davey 1969; Vaartaja 1967; Warcup 1957). However, in many cases, saprophytes are more mobile and colonize fumigated soil at higher levels than pathogens (James and Gilligan 1985, 1986; Papavizas 1985; Vaartaja 1967). Unfortunately, in some cases, pathogens are reintroduced into fumigated soil at high levels, especially when they occupy adjacent, non-fumigated soil or are introduced during sowing (James 1990; Smith and Bega 1966).

Soil fumigation with MBC has been successful at the Coeur d'Alene Nursery and growers are quite satisfied with seedling numbers and quality produced after fumigation was initiated. However, recent concerns about environmental impacts within, and adjacent to, the nursery resulting from MBC treatment (including possible fumigant leakage and drift into nearby residential areas), prompted growers to look for alternatives to MBC. One of the most promising fumigant alternatives to MBC was a granular formulation of dazomet (Basamid®). In some cases, this fumigant has been as effective as MBC in controlling soil-borne pathogens (Campbell and Kelpsas 1988; Miller and Norris 1970). It is not a volatile gas that requires tarping like MBC. Dazomet is applied directly to the soil surface, disked in with a rototiller, and sealed with topical applications of water. When water contacts the granules, the fumigant volatilizes and kills nearby organisms. Treatment costs for dazomet and MBC are usually similar.

Because of the potential usefulness of dazomet as a soil fumigant at the Coeur d'Alene Nursery, an evaluation was conducted to determine effects of this fumigant on soil pathogen populations, seedling disease, and seedling production. A different field treated with MBC in another portion of the nursery was simultaneously evaluated.

MATERIALS AND METHODS

Granular formulation of dazomet was evaluated in Field 10, located in the southcentral portion of the nursery, commencing in 1986. This field comprises approximately 8 acres which were fallow for much of 1986, but had cover crops of rye and oats during 1985. Most of the field was fumigated with dazomet in September, 1986. The application rate was about 350 pounds per acre. One week prior to treatment, 10 soil samples were collected from a portion of the field to be fumigated, and 10 from an adjacent area that was not being fumigated. These and all subsequent soil samples were collected at 20-foot intervals along a transect in the center of each section (sections were delimited by irrigation equipment). Each sample consisted of a composite of five cores of soil taken to a depth of 6 inches (core diameter = 23mm). Samples included a central core and four cores collected about 1 foot from the central core in each of four cardinal directions. Soil was placed in a paper bag, thoroughly mixed, and kept refrigerated until analysis.

The following laboratory procedures were used for processing all soil samples:

Soil was initially sieved to remove large rocks, pieces of organic matter, and soil aggregations. From each soil sample, a 5 grams subsample was used to calculate oven-dry weight, which provided a standard basis for comparison. For this determination, samples were dried at about 100°C for at least 24 hours or until weight of the sample had stabilized (all excess moisture removed). For analysis of pathogen populations, field-moist soil was used, but fungal populations were reported on an oven-dry weight basis. Two groups of potentially pathogenic fungi (*Fusarium* and *Pythium*) were assayed from each soil sample. For assay of *Fusarium* populations, 0.5 grams of soil was weighed from each sample, combined with 100 milliliter of 0.3 percent water agar (WA) and thoroughly mixed. One milliliter of the solution was placed on each of three plates of a selective agar

medium for *Fusarium* (Komada 1975) and spread uniformly over the agar surface with a sterile glass rod. Plates were incubated at about 24°C under diurnal cycles of cool, fluorescent light for 5 days. *Fusarium* colonies were determined by their morphology on the selective medium and colony-forming units per gram of soil calculated. Similar procedures were used for assay of *Pythium* populations except 5.0 grams of soil were initially introduced into WA and the solution placed on a selective *Pythium* agar medium consisting of V-8 juice amended with pimaricin, rifamycin, ampicillin, and pentachloronitrobenzene. Plates with soil were incubated at about 24°C for 3 days in the dark. After incubation, excess soil was carefully washed from the surface of plates and number of *Pythium* colonies determined. Colonies were identified on the basis of their diameter after 3 days (15-20 mm), their feathery margin, and the fact that they grew within rather than superficially on the surface of agar. Colony-forming units per gram of soil were then calculated.

Approximately one month after dazomet fumigation, post-treatment soil samples (same number in approximately the same locations) were collected and analyzed. Additional soil samples were collected in Field 10 just prior to sowing (May 1987), at the end of the first growing season (October 1987), at the beginning of the second growing season (May 1988), and at the end of the second growing season just before lifting (October 1988). All samples were collected and analyzed as described above.

During the same time, the evaluation of Field 10 was conducted. Field 1, located in the northwest portion of the nursery, was also evaluated. Most of this field had been fumigated with MBC in August 1986. A small strip about 50 feet wide on the southern border of the field was left untreated. Pre-fumigation and post-fumigation soil samples were not obtained from Field 1. However, the other soil samples described for Field 10 (pre-sowing, end of first growing season, beginning and end of second growing season) were also collected and analyzed for Field 1. Samples were collected from both fumigated and non-fumigated portions of this field.

During May 1987, beds were formed and seed sown in both Fields 1 and 10. For evaluation purposes, the same seedlots of western white pine (*Pinus monticola* Dougl.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and western larch (*Larix occidentalis* Nutt.) were sown in both fumigated and non-fumigated portions of both fields. After sowing, plots were established within each conifer species and delimited with wooden stakes and string. Five plots (each composed of 3 linear ft. - 10.5 ft.^{2}) were located at 20-foot intervals within each conifer species in fumigated and non-fumigated portions of both fields (10 plots/species/field or a total of 60 plots). Subsequent seedling measurements were taken within these plots.

Within the center of each plot, a subplot 1 foot long and 1.5 feet wide was delimited for determining seedling emergence and levels of post-emergence damping-off about 4 weeks after sowing. Damping-off losses were calculated as percentages of emerged seedlings. Examples of damped-off seedlings were collected and analyzed for presence of associated fungi. Procedures for this analysis consisted of thoroughly washing samples to remove soil particles, surface sterilization of roots in a 10 percent bleach (0.525% aqueous sodium hypochlorite) solution for 1 minute followed by rinsing with sterile water, and incubating on Komada's medium as described for soil samples. Potentially pathogenic fungi emerging from roots were identified using several taxonomic guides (Booth 1966; Domsch and others 1980; Dorenbosch 1970; Nelson and others 1983).

Occurrence of seedling disease was monitored periodically within plots throughout the 2-year growth cycle. Seedling counts were taken 3 months after sowing, at the end of the first growing season, at the beginning of the second growing season, and at the end of the second growing season, just prior to lifting. Losses attributed to disease, bird damage, winter damage, and unknown causes were determined. Cumulative disease (all disease over the 2-year growth cycle expressed as a percentage of emerged seedlings) was calculated.

At the time of lifting, 20 seedlings from each plot were randomly collected for measurement and isolation of *Fusarium* spp. from their roots. Previous investigations at the nursery (James and Gilligan 1988) had shown that

non-symptomatic infection of bareroot seedlings might be common. Heights (from groundline to the tip of their terminal buds) and calipers of selected seedlings were measured. Oven-dry weights (biomass production) of above-ground portions (foliage, stem, and branches) were also determined. Root systems were sampled for infection by *Fusarium* spp. by randomly selecting 10 root tips which had been excised, washed, and surface sterilized, and incubating them on Komada's medium. Selected isolates were tranferred to potato dextrose (PDA) and carnation leaf (CLA) agar for identification using the taxonomic scheme of Nelson and others (1983). Percentage of seedlings infected and colonization intensity (percent colonization of all sampled root tips) by *Fusarium* spp. were determined.

Within each species, all data were analyzed using paired "t" tests comparing fumigated versus non-fumigated treatments. All percentages underwent arc-sin conversions prior to analysis.

RESULTS AND DISCUSSION

Data tables summarizing results are included in the Appendix. Populations of *Fusarium* and *Pythium* for samples taken in both fields are summarized in Table 1. Pre-treatment and post-treatment values for *Fusarium* in Field 10 (not sampled in Field 1) were: pre-treatment, non-fumigated = mean: 140 colony-forming units (cfu)/g, range: 0-543; pre-treatment, fumigated = mean: 167 cfu/g, range 0-303; post-treatment, non-fumigated = mean: 120 cfu/g, range 0-270; post-treatment, fumigated = mean and range: 0. Correspondingly, populations of *Pythium* were: pre-treatment, non-fumigated = mean: 201 cfu/g, range 117-322; pre-treatment, fumigated = mean: 149 cfu/g, range 62-226; post-treatment, non-fumigated = mean: 173 cfu/g, range 6-243; post-treatment, fumigated = mean: 1 cfu/g, range 0-6.

Fusarium levels had risen to 114 cubic foot unit per gram by the time of sowing (the spring following fumigation) in Field 10 (Table 1). However, these levels did not greatly increase throughout the 2-year growing cycle. Higher levels of *Fusarium* were detected in the spring compared to those assayed in the fall. Overall levels of *Fusarium* were quite low in all soil samples, particularly in fumigated portions of Field 10; these levels approximated those detected at other times in this and other parts of the nursery (James and Gilligan 1985, 1986). Differences in *Fusarium* populations between fumigated and non-fumigated portions of Field 10 were statistically significant (all statistical significance reported at $P=0.05$); overall levels in non-fumigated soil was almost five times those in fumigated soil.

Pythium levels in Field 10 were proportionately higher than *Fusarium*, i.e., potential problems from *Pythium*-associated diseases may be expected when populations exceed 100 cubic foot unit per gram, whereas the corresponding level for *Fusarium* is about 1000 cubic foot unit per gram (Hildebrand and Dinkel 1988; F. McElroy, personal communication). In other words, it takes more *Fusarium* inoculum per gram of soil than *Pythium* to cause similar amounts of disease. Non-fumigated portions of Field 10 exceeded this threshold during each sample period (Table 1). However, fumigated portions were well below threshold levels throughout the 2-year sample period. Lower *Pythium* levels were detected in the fall than in the spring in fumigated portions of the field. *Pythium* populations were significantly lower in fumigated soil during each sampling period.

Lower levels of both *Fusarium* and *Pythium* were detected in Field 1 (Table 1). Treatment with MBC completely eliminated all *Fusarium* and *Pythium* propagules. No *Fusarium* propagules were detected in fumigated soil during the 2-year sampling period. *Pythium* spp. were detected at very low levels, but only during the second growing season. Treatment with MBC significantly reduced populations of *Fusarium* and *Pythium* and these populations remained significantly below those in non-fumigated portions of Field 1 throughout the 2-year growth cycle.

These results indicated that dazomet was not as effective as MBC in limiting populations of *Fusarium* and *Pythium* throughout the time required to produce bareroot conifer seedlings. However, background levels of these organisms (non-fumigated areas) were higher in the field treated with dazomet than in the field treated with MBC. Also, pathogen populations in dazomet-treated soil never exceeded "disease threshold" levels. In other studies (Campbell and Kelpsas 1988; Hoffman and Williams 1988), pathogen populations either increased rapidly in soil fumigated with dazomet or were not initially reduced as much as with treatment with MBC. Therefore, it seems that MBC more effectively eliminates pathogens and populations remain lower longer than in soil treated with dazomet. Fumigant penetration limitations of dazomet, rather than problems of toxicity to pathogens, are likely involved (Kolbezen and others 1974; Munnecke and Van Gundy 1979).

Data on establishment of white pine, Douglas-fir, and western larch seedlings in fumigated and non-fumigated soil are summarized in Table 2. White pine seed germination and seedling emergence occurred over a long period of time in the spring and early summer following sowing. Resulting seedbed densities of this species were consistently less than the other two species. This may have been due to higher levels of damping-off occurring in white pine (Table 3). Prolonged seed germination and seedling establishment would result in longer periods of exposure and seedling susceptibility to damping-off fungi (Spaulding 1914). Significant effects of fumigation on seedling establishment and post-emergence damping-off were only detected for white pine (Tables 2 and 3). For the other two species, small insignificant increases in seedling emergence were detected. Damping-off losses were so low in both fumigated and non-fumigated areas that fumigation effects were not detected.

Bird feeding (clipping off tops or cotyledons) accounted for early seedling losses, particularly of white pine in Field 1 (5-10% of the emerged seedlings). Losses of Douglas-fir and western larch ranged from 0-1.5% and were likewise higher in Field 1. Differences in bird damage might be due to their preference for white pine and their greater abundance in Field 1.

Cumulative disease over the entire growth cycle (Table 4) was highest for white pine, particularly in non-fumigated portions of both fields. Significantly higher disease was also detected for Douglas-fir in non-fumigated portions of Field 10. Disease levels for western larch were so low throughout both fields that fumigation effects could not be detected. Maximum disease levels rarely exceeded 10 percent even in non-fumigated soils. Disease losses were negligible in MBC treated soil and slightly higher in dazomet treated areas. Higher disease levels in dazomet-treated areas may have been due to higher background levels of soil pathogens (Table 1).

All sampled healthy-appearing seedlings were infected with *Fusarium* spp. in both fumigated and non-fumigated portions of Field 10. However, colonization intensity (percentage of root tips colonized) was significantly less in fumigated portions of the field (Table 5). Seedlings grown in Field 1 were infected with *Fusarium* at lower levels, i.e., 91 percent of the seedlings in non-fumigated portions were infected, whereas only 14 percent of the seedlings grown in fumigated soil became infected. Colonization intensity was also significantly less in seedlings grown in MBC-fumigated soil (Table 5).

The most commonly isolated *Fusarium* spp. from seedlings in Field 10 was *F. oxysporum* Schlecht., comprising about 69 percent of the isolates. Other isolated species isolated included *F. acuminatum* Ell. & Ev., *F. sambucinum* Fuckel, *F. avenaceum* (Fr.)Sacc., and *F. tricinctum* (Corda)Sacc. However, in Field 1, combinations of *F. acuminatum*, *F. avenaceum*, and *F. sambucinum* comprised about 80 percent of the isolates obtained from seedlings; the remaining 20 percent were *F. oxysporum*. All of these fungal species have previously been isolated from conifer seedlings (James and others 1989a). However, only *F. oxysporum* and *F. acuminatum* are usually considered important pathogens (James and Gilligan 1984; James and others 1986, 1989b). Less occurrence of *F. oxysporum* in Field 1 might indicate that the *Fusarium* population in this field was composed of mostly saprophtyic isolates, whereas the population in Field 10 might have been represented by higher

proportions of pathogenic isolates (Bloomberg 1965). This conclusion was substantiated by the higher disease levels detected in Field 10 (Table 4).

Other potentially pathogenic fungi isolated from diseased seedlings included *Cylindrocarpon didymum* (Hartig)Wollenw., *C. tenue* Bugn., *Phoma eupyrena* Sacc., and *P. herbarum* Westend. Although each of these species have previously been associated with conifer seedling diseases (Booth 1966; Domsch and others 1980; Dorenbosch 1970; James 1988; James and Hamm 1985), they were not encountered as frequently as *Fusarium* in the present evaluation.

White pine and western larch seedlings grown in fumigated soil were significantly taller than those grown in non-fumigated soil (Table 6). However, Douglas-fir seedlings were significantly shorter in fumigated portions of both fields. Caliper and above-ground biomass of seedlings were not significantly affected by soil fumigation (Tables 7 and 8). White pine seedlings grown in Field 1 were usually taller than those grown in Field 10. However, similar differences were not found for either Douglas-fir or western larch.

Soil fumigation may cause either positive or negative growth responses in seedlings. Increased growth might result from reduced levels of weakly-pathogenic fungi ("root nibblers" that slowly deteriorate root systems over time) resulting from fumigation (Munnecke and others 1978; Smith and Bega 1966). However, decreased growth may be due to detrimental effects of fumigation on mycorrhizal fungi or antagonists/competitors of pathogens and chemical toxicity to seedlings (Johnson and Zak 1977; Wensley 1953).

In conclusion, this evaluation indicated that dazomet was an effective fumigant at the Coeur d'Alene Nursery, but generally not as effective as MBC. Dazomet significantly reduced soil pathogen populations and high quality seedlings were produced in treated soil. However, it should be noted that background levels of pathogens, particularly *Fusarium*, were low prior to fumigation. Such low levels at the nursery may be due to recurrent cycles of fumigation with MBC that occurred in the past. These treatments may have lowered levels of *Fusarium* throughout much of the nursery. It is possible that pathogen levels might gradually increase if dazomet replaces MBC as the primary fumigant, since the former does not reduce populations as effectively as the latter. The situation with *Pythium* is somewhat different. Background levels of these potentially-pathogenic fungi are proportionately higher; they may continue to increase over time if dazomet is used as the primary fumigant.

Of course, the bottom line is production of high quality seedlings in the numbers needed for reforestation. As yet, soil populations of pathogens are apparently not high enough to significantly impact seedling production. However, a point of concern found in this evaluation was the high number of healthy-appearing seedlings infected with *Fusarium*. Since greater amounts of root colonization were detected in the field treated with dazomet, it is possible that these seedlings may have more problems with survival and growth once outplanted. It is possible that if seedlings are sufficiently stressed prior to or during the first growing season following outplanting, fusaria on their roots may affect survival. On the other hand, if seedlings are not stressed, root infection with *Fusarium* may have little or no effect.

It is important that growers at the nursery continue to carefully monitor soil populations of potential pathogens, as well as disease levels to ensure continued efficacy of dazomet. If production problems result from continued use of this fumigant, alternatives might be needed, including occasional reuse of MBC.

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APPENDIX

Table 1. Effects of soil fumigation on populations of *Fusarium* and *Pythium* within Fields 1 and 10 of the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

Sample	Average Colony-Forming Units Per Gram					
	Fusarium			*Pythium*		
	Non-fumigated	Fumigated	"t"[1]	Non-fumigated	Fumigated	"t"[1]
FIELD 10 [2]						
Pre-Sowing	421	114	2.54†	165	40	8.11†
End 1st Season	645	38	4.21†	103	19	7.04†
Begin 2nd Season	706	227	6.73†	157	44	7.22†
End 2nd Season	322	75	2.60†	165	17	9.19†
All Samples	524	114	7.10†	148	30	15.03†
FIELD 1 [3]						
Pre-Sowing	31	0	2.71†	64	0	3.10†
End 1st Season	18	0	2.26†	100	0	4.74†
Begin 2nd Season	4	0	1.00‡	40	1	7.38†
End 2nd Season	41	0	2.71†	91	8	4.28†
All Samples	24	0	4.36†	74	2	7.81†

[1] "t" value from paired t tests: † statistically significant (fumigated vs. non-fumigated) at P=0.05; ‡ statistically not significant.

[2] Fumigated with dazomet in fall 1986; sown in spring 1987.

[3] Fumigated with methyl bromide/chloropicrin in fall 1986; sown in spring 1987.

Table 2. Effects of soil fumigation on emergence of white pine, Douglas-fir and western larch seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Number of Emerged Seedlings						
	Fumigation Treatment						
	Non-Fumigated			Fumigated			
Conifer Species	Mean	Range	Std. Dev.	Mean	Range	Std. Dev.	"t"[1]
FIELD 10 [2]							
White Pine	192	141-218	31.0	307	249-443	77.7	2.44†
Douglas-fir	350	242-444	84.5	355	274-478	83.6	0.25‡
Western Larch	405	215-536	124.7	414	145-645	195.8	0.14‡
FIELD 1 [3]							
White Pine	105	82-118	14.6	196	154-240	33.2	6.06†
Douglas-fir	296	238-362	45.0	325	306-364	23.2	1.00‡
Western Larch	295	195-382	77.7	370	318-426	48.3	1.40‡
FIELDS 1 & 10 (Combined)							
White Pine	148	82-218	51.2	251	154-443	81.1	4.37†
Douglas-fir	323	238-444	70.0	340	274-478	59.9	1.02‡
Western Larch	350	195-536	113.8	392	145-645	136.43	1.06‡

[1] "t" value from paired t tests: † = statistically significant (fumigated vs. non-fumigated) at P = 0.05.; ‡ = not statistically significant.

[2] Fumigated with dazomet in fall 1986; sown in spring 1987.

[3] Fumigated with methyl bromide/chloropicrin in fall 1986; sown in spring 1987.

Table 3. Effects of soil fumigation on post-emergence damping-off of white pine, Douglas-fir, and western larch seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Percentage of Emerged Seedlings Damped-off[1]						
	Fumigation Treatment						
	Non-fumigated			Fumigated			
Conifer Species	Mean	Range	Std. Dev.	Mean	Range	Std. Dev.	"t"[2]
FIELD 10 [3]							
White Pine	3.3	0.9-6.4	0.5	0.8	0.4-1.6	0.1	2.96†
Douglas-fir	0.8	0-1.6	0.3	0.5	0-1.1	0.3	0.61‡
Western Larch	0.9	0-2.0	0.3	0.2	0-0.6	0.1	1.49‡
FIELD 1 [4]							
White Pine	0.7	0 -2.0	0.4	0.3	0-0.6	0.1	0.54‡
Douglas-fir	0.3	0 -0.8	0.2	0.6	0-1.3	0.2	0.60‡
Western Larch	0.1	0 -0.3	0.3	0.3	0-1.3	0.2	0.94‡
FIELDS 1 & 10 (Combined)							
White Pine	2.0	0-6.4	4.8	0.5	0-1.6	2.2	2.08†
Douglas-fir	0.5	0-1.6	2.7	0.5	0-1.3	2.6	0.08‡
Western Larch	0.5	0-2.0	2.9	0.2	0-1.3	2.2	0.70‡

[1] Percentages underwent arc-sin conversions prior to analysis.

[2] "t" values from paired t tests: † = statistically significant (fumigated vs. non-fumigated) at P=0.05; ‡ = not statistically significant.

[3] Fumigated with dazomet in fall 1986; sown in spring 1987.

[4] Fumigated with methyl bromide/chloropicrin in fall 1986; sown in spring 1987.

Table 4. Effects of soil fumigation on cumulative disease of white pine, Douglas-fir, and western larch seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Percentage of Emerged Seedlings[1]						
	Fumigation Treatment						
	Non-fumigated			Fumigated			
Conifer Species	Mean	Range	Std. Dev.	Mean	Range	Std. Dev.	"t"[2]
FIELD 10 [3]							
White Pine	10.9	8.8-14.0	0.1	4.2	2.2-5.4	0.1	7.16†
Douglas-fir	10.8	8.0-12.4	0.1	5.9	4.1-8.4	0.1	5.37†
Western Larch	1.6	0.5-2.8	0.1	0.7	0-2.1	0.3	1.83‡
FIELD 1 [4]							
White Pine	8.0	2.4-13.5	0.8	2.1	0.6-3.9	0.2	2.78†
Douglas-fir	1.7	0.5-4.3	0.3	0.6	0.3-1.3	0.1	1.74‡
Western Larch	1.9	0.8-4.1	0.3	0.6	0.3-1.2	0.1	2.52†
FIELDS 1 & 10 (Combined)							
White Pine	9.5	2.4-14.0	4.0	3.1	0.6-5.4	2.9	5.35†
Douglas-fir	5.3	0.5-12.4	6.6	2.6	0.3-8.4	5.2	4.09†
Western Larch	1.7	0.5-4.1	2.5	0.7	0 -2.1	2.2	3.20†

[1] Percentages underwent arc-sin conversion prior to analysis.

[2] "t" values from paired "t" tests; † = statistically significant (fumigated vs. non-fumigated) at P = 0.05; ‡ = not statistically significant.

[3] Fumigated with dazomet in fall 1986; sown in spring 1987.

[4] Fumigated with methyl bromide/chloropicrin in fall 1986; sown in spring 1987.

Table 5. Effects of soil fumigation on root infection of non-diseased white pine, Douglas-fir, and western larch seedlings with *Fusarium* spp. at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Percentage Root Colonization[1]						
	Fumigation Treatment						
	Non-fumigated			Fumigated			
Conifer Species	Mean	Range	Std. Dev.	Mean	Range	Std. Dev.	"t"[2]
FIELD 10 [3]							
White Pine	77.5	66.9-85.0	0.7	51.9	43.9-60.1	0.3	5.41†
Douglas-fir	70.0	58.0-76.1	0.6	52.6	41.0-69.1	1.5	4.27†
Western Larch	67.6	45.0-75.0	1.7	50.9	45.0-53.0	0.1	2.72†
FIELD 1 [4]							
White Pine	37.1	25.0-47.0	0.7	10.5	10.0-12.0	0.1	7.51†
Douglas-fir	26.2	20.0-37.1	0.6	10.0	10.0-10.0	0	6.49†
Western Larch	26.1	18.9-36.1	0.7	10.0	10.0-10.0	0	5.02†
FIELDS 1 & 10 (Combined)							
White Pine	60.4	25.0-85.0	13.5	31.3	10.0-60.1	14.6	8.88†
Douglas-fir	47.9	20.0-76.1	14.3	28.9	10.0-69.1	15.5	7.60†
Western Larch	51.4	18.9-75.0	14.2	33.4	10.0-53.0	14.1	4.55†

[1] Percentages underwent arc-sin conversions prior to analysis. Values are percent of all sampled root pieces. (colonization intensity).

[2] "t" values from paired "t" tests: † = statistically significant (fumigated vs. non-fumigated) at P=0.05; ‡ = not statistically significant.

[3] Fumigated with dazomet in fall 1986; sown in spring 1987.

[4] Fumigated with methyl bromide/chloropicrin in fall 1986; sown in spring 1987.

Table 6. Effects of soil fumigation on heights of 2-0 white pine, Douglas-fir and western larch seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Seedling Height (mm)						
	Fumigation Treatment						
	Non-fumigated			Fumigated			
Conifer Species	Mean	Range	Std. Dev.	Mean	Range	Std. Dev.	"t"[1]
FIELD 10 [2]							
White Pine	60.9	54.8-73.2	7.3	59.3	51.1-68.2	7.0	0.28‡
Douglas-fir	151.1	133.2-164.5	12.7	121.1	107.5-130.4	9.1	7.65†
Western Larch	312.0	285.3-337.5	20.2	333.2	285.2-392.7	40.5	2.25†
FIELD 1 [3]							
White Pine	74.5	67.3-81.6	5.6	89.4	85.6-93.6	3.5	4.24†
Douglas-fir	159.1	141.2-175.0	13.6	131.9	141.2-175.0	13.6	3.52†
Western Larch	275.6	253.4-297.8	16.0	353.8	279.3-478.3	75.0	1.98‡
FIELDS 1 & 10 (Combined)							
White Pine	67.7	54.8-81.6	9.4	74.4	51.1-93.6	16.7	1.57‡
Douglas-fir	155.1	133.2-175.0	13.1	126.5	107.5-137.9	9.3	6.95†
Western Larch	293.8	253.4-337.5	25.7	343.5	279.3-478.3	57.9	2.33†

[1] "t" values from paired "t" tests: † = statistically significant (fumigated vs. non-fumigated) at P=0.05; ‡ = not statistically significant.

[2] Fumigated with dazomet in fall 1986; sown in spring 1987.

[3] Fumigated with methyl bromide/chloropicrin in fall of 1986; sown in spring 1987.

Table 7. Effects of soil fumigation on caliper of 2-0 white pine, Douglas-fir and western larch seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Seedling Caliper (mm)						
	Fumigation Treatment						
	Non-fumigated			Fumigated			
Conifer Species	Mean	Range	Std. Dev.	Mean	Range	Std. Dev.	"t"[1]
FIELD 10 [2]							
White Pine	2.77	2.55-3.20	0.25	2.96	2.70-3.07	0.16	1.21‡
Douglas-fir	4.17	3.80-4.50	0.25	4.03	3.30-4.78	0.57	0.58‡
Western Larch	4.49	3.90-5.25	0.49	4.94	4.35-5.22	0.34	1.88‡
FIELD 1 [3]							
White Pine	3.23	2.85-3.65	0.35	3.47	3.35-3.75	0.16	1.20‡
Douglas-fir	3.38	2.90-4.32	0.57	3.51	3.35-3.65	0.13	0.42‡
Western Larch	4.68	3.99-5.45	0.58	4.59	3.91-5.79	0.75	0.15‡
FIELDS 1 & 10 (Combined)							
White Pine	3.00	2.55-3.65	0.37	3.21	2.70-3.75	0.31	1.79‡
Douglas-fir	3.78	2.90-4.50	0.59	3.77	3.30-4.78	0.48	0.05‡
Western Larch	4.58	3.90-5.45	0.52	4.76	3.91-5.79	0.58	0.58‡

[1] "t" values from paired "t" tests: † = statistically significant (fumigated vs. non-fumigated) at P=0.05; ‡ = not statistically significant.

[2] Fumigated with dazomet in fall 1986; sown in spring 1987.

[3] Fumigated with methyl bromide/chloropicrin in fall 1986; sown in spring 1987.

Table 8. Effects of soil fumigation on foliage dry weights of 2-0 white pine, Douglas-fir, and western larch seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Foliage Dry Weight (g)[1]						
	Fumigation Treatment						
	Non-fumigated			Fumigated			
Conifer Species	Mean	Range	Std. Dev.	Mean	Range	Std. Dev.	"t"[2]
FIELD 10 [3]							
White Pine	1.49	1.22-2.13	0.37	1.60	1.34-1.86	0.25	0.48‡
Douglas-fir	3.82	3.11-4.29	0.49	3.40	2.52-4.40	0.78	1.55‡
Western Larch	3.94	3.24-5.24	0.80	4.26	2.97-5.38	0.86	0.72‡
FIELD 1 [4]							
White Pine	2.36	1.55-3.29	0.66	2.90	2.81-3.07	0.10	1.95‡
Douglas-fir	2.89	2.08-3.68	0.73	2.35	2.13-2.63	0.21	1.39‡
Western Larch	3.53	2.37-4.46	0.92	3.55	2.46-5.36	1.18	0.03‡
FIELDS 1 & 10 (Combined)							
White Pine	1.92	1.22-3.29	0.68	2.25	1.34-3.07	0.71	1.76‡
Douglas-fir	3.35	2.08-4.29	0.76	2.87	2.13-4.40	0.77	2.14†
Western Larch	3.74	2.37-5.24	0.84	3.91	2.46-5.38	1.04	0.35‡

[1] Oven-dry weights of seedling tops (includes foliage, stem, and branches).

[2] "t" values from paired "t" tests: † = statistically signficant (fumigated vs. non-fumigated)at P=0.05; ‡ = not statistically significant.

[3] Fumigated with dazomet in fall 1986; sown in spring 1987.

[4] Fumigated with methyl bromide/chloropicrin in fall 1986; sown in spring 1987.